

Switched Carrier Experiments

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This article describes experiments to produce a practical system for time-sharing a klystron amplifier between two up-link frequencies. Attempts to produce intermodulation products in the Deep Space Instrumentation Facility (DSIF) receiver passband and observations on intermodulation products at a DSIF station (Pioneer Deep Space Station) are described.

I. Introduction

The DSIF has a requirement in support of the *Viking* Mission for simultaneous transmission of two carriers from one 64-m antenna. These carriers would be separated by approximately 5 MHz and carry ranging modulation. The power level required is a minimum of 40 kW in each carrier and its associated sidebands. The 400-kW transmitter can supply this easily if excitation is supplied at the two frequencies, but past experience has shown that intermodulation (IM) products in the receiver passband well above receiver threshold are generated by this approach. These products are generated whenever two carriers are present in a nonlinear system. There is evidence that they are generated in the waveguide equipment or antenna structure.

If the excitation could be switched so that the klystron and antenna see only one carrier at a time, these intermodulation products would not be generated.¹ The Goldstone Development Support Group of the RF Systems Development Section has been performing experiments to determine the feasibility of this method.

¹Proposed by M. Easterling.

This experiment to investigate the feasibility of time-sharing a klystron amplifier was conducted in several parts:

- (1) Development of 66-MHz switch.
- (2) Investigation of DSIF multiplier chain under switched-carrier conditions.
- (3) Development of 2115-MHz switching techniques
- (4) Investigation of klystron performance under switched-carrier conditions.
- (5) Investigation of klystron and antenna performance under simultaneous carrier conditions.

A. Development and Performance of a 66-MHz Switch

The diode switch described in Ref. 1, p. 82 and Ref. 2 was unsatisfactory because of internally generated IM products created by the diodes in the switch. These IM products were -22 dB relative to the two input carriers. Also the switch described with its associated driver did not have independent control of each frequency on and off times.

A pair of commercial diode switches (Relcom S2) were procured and suitable driver units were fabricated (Fig. 1). Although the switch is a SPDT switch, two switches and associated driver units were used to allow independent control of each frequency "on" and "off" times. Each Relcom switch and its associated driver was driven with a pulse generator. Figure 2 is a block diagram of the equipment used to investigate the performance of the switches and the DSIF Block III multiplier chain.

The Relcom switches performed satisfactorily in this configuration. A typical 66 MHz spectrum is shown in Fig. 3. Time domain is shown in Figs. 4 and 5. However, the DSIF Block III multiplier chain distorted the output spectrum and generated excessive noise in the S-band spectrum. The strongest spectral line at the output of the multiplier chain was, in general, *not* the carrier frequency but the first switching sideband (Fig. 6). Although it has not been fully investigated, this phenomenon is thought to be due to the self-bias circuits in the multiplier.

B. S-Band Switching

Because of the unpredictable performance of the DSIF Block III Multiplier under switched-carrier conditions, it was decided to accomplish the switching at the output of the multiplier. This was accomplished by the equipment shown in Fig. 7. Hewlett-Packard Model 8732A PIN-diode modulators were used as switches. A fixed bias of -4 Vdc applied to the switches resulted in best performance. As with the 66-MHz switches, each S-band switch was independently controlled by a pulse generator. The use of isolators and a hybrid isolated the two switches so that no interaction was detected. Figures 8 and 9 show the spectrum and envelopes obtained by S-band switching. By adjustment of the switching voltages, independent control of the duty cycle of each carrier is possible.

The switched-carrier signal generated in this manner was used to drive a Model 5K70SG klystron amplifier. The 5K70SG klystron is a 20-kW CW output klystron used in both MSFN and DSIF 20-kW transmitters. Also, this klystron utilizes the same electron beam optics as the Eimac X3075 klystron, which is presently used in the DSIF 400-kW transmitters. It is expected that the 5K70SG klystron performance under these conditions will be representative of the X3075 klystron performance.

When driving the klystron amplifier with one carrier keyed at a 500-kHz rate (analogous to 100% square wave amplitude modulation), the even-order sideband suppression is degraded when amplified by the klystron. When both carriers are present, the even-order sideband sup-

pression is improved somewhat. Figures 10 and 11 show input and output spectrums under single-switched carrier and dual-switched carrier, respectively. Operating the klystron saturated produced the most severe degradation of the even-order sideband suppression. The spectra in Fig. 11 were measured with the klystron operating under saturated conditions.

In order to determine if there would be any degradation in DSIF system performance when operating under switched carrier conditions, a DSIF S-band Cassegrain monopulse/traveling-wave maser (SCM/TWM) microwave subsystem was diplexed using switched-carrier drive. The particular SCM used in these tests was a unit returned from service because of excessive noise bursts. Using wideband noise instrumentation (Fig. 12), no degradation of system temperature was noted when operating in the switched-carrier mode.

C. Attempts to Generate a Receive Band IM Product

Attempts were made to produce a detectable intermodulation product in the receiver passband. Transmitter frequencies were selected so that the 240/221 turnaround ratio of one frequency (2113.3125) would be within range of the Microwave Test Facility phase-lock receiver. The second transmitter frequency (2116.3919) was selected so that a predicted intermodulation distortion product would also be within the receiver's tuning range.

By operating this klystron well into saturation, maximum intermodulation distortion was observed. However, we were unable to detect any intermodulation products stronger than the receiver threshold (-170 dBmW). Measurement of IM product amplitudes in the vicinity of the two carriers showed each successive IM product was, on the average, 3.8 dB below the previous one. By extrapolating these data to the DSIF receiver band, the IM product would be 220 dB down from the carriers, or approximately -150 dBmW. The isolation between the transmitter and maser is typically 130 to 160 dB, so IM products generated *in the klystron* would be expected to be well below receiver threshold.

Attempts were made to generate IM products by placing various nonlinear devices in the near-field of the Cassegrain feed horn. The following types of nonlinear devices were tried:

1. *PN-type junctions (such as are found in semiconductors)*. An example of this would be a microwave mixer diode, such as a type 1N21B. In this attempt, a PN silicon rectifier junction (1N4005 diode with the leads forming

both half-wave dipoles and full-wave resonant loops) were placed approximately 0.3 m in front of the feed horn. Although increases in system temperature were noted (~ 50 to 100°K) as the diodes started conducting, no IM products were detected. The next experiment used a WR-430 to coax transition, a 1N21 crystal holder pointed down the feed at an approximate 0.3-m distance. Again, temperature increases were noted, but no IM products detected.

2. Corroded metal joints and dissimilar metal joints. In this experiment, metal strips of aluminum and OFHC copper ($25 \times 3 \times 0.32$ cm approximate dimensions) were joined together with approximately 10 cm of overlap with stainless steel screws and placed 0.3 m in front of the feed horn. One of these test pieces was fresh, and the other test piece was dipped into a nitric-sulphuric acid solution (this solution is normally used for cleaning fabricated copper and copper-based alloy parts) to induce joint corrosion. Both of these test pieces, when placed in the beam of the feed horn produced 50 to 100°K noise bursts, but no detectable IM products.

3. Ionization. To simulate the nonlinear phenomenon that would be present in corona discharge, neon lamps and fluorescent lighting tubes were suspended in the beam of the feed horn. With power output of approximately 1 kW, the 50 to 100°K noise bursts were observed. Increasing the power resulted in an erratic system temperature increase as the gas tube ionized. Again, no IM products were detected.

4. Arcs. To produce an RF arc in the feedhorn beam, a spark gap was made of two 6.35 mm (0.25 in.) stainless steel rods placed $\lambda g/4$ from a short in WR-430 waveguide. The gap was centered in the waveguide at the point of maximum electric field. The gap was set to approximately 1 mm spacing and suspended approximately 0.3 m above the feedhorn with the open end of the waveguide. Due to the weight of the gap assembly, it was necessary to use a 4×9 cm ("two-by-four") Douglas fir beam to suspend the arc gap. This arc gap fired at approximately 5 kW transmitter power. The transmitter was operated at 15 kW total power output during the search for an IM product. Although no IM product was detected, the fir beam scorched and started to burn. The power density encountered was sufficient to burn the wood in the center of the beam.

All of the above nonlinear devices produced broadband noise, but no detectable intermodulation products were

produced. At the present time we have no explanation for the negative results. All of the above devices should have produced IM products but none were detected.

D. IM Product Experiments at DSS 11

Earlier work (Ref. 3) measured IM products on the DSS 11 26-m antenna when operating under dual carrier conditions. Time was made available at DSS 11 to verify these results and to attempt to learn more about the nature of IM product generation. Because the station was only available in the MSFN configuration, MSFN frequencies were used for these experiments. The frequencies used for transmission were 2101.8021 and 2106.5517 MHz. A stable (in frequency) IM product was received on 2282.2869 MHz, which agrees with a predicted IM product frequency. The amplitude of this product varied rapidly ($T < 1$ sec) between -130 and -150 dBmW, with a signal strength normally around -140 dBmW. To conduct the tests at DSS 11, the incoherent AGC was on one channel of a chart recorder and the coherent AGC with a 4.5-Hz bandwidth recorded on another channel of the same chart recorder. One of the event markers was used to indicate receiver lock conditions. The incoherent AGC channel corresponds to system temperature. Figure 13 shows a portion of this chart recorder graph and shows the calibrations of the coherent AGC channel. Figure 14 shows the noise bursts and amplitude of the IM products. It can be seen that the IM product amplitude has a definite positive correlation with the system temperature bursts. Individual footsteps of a man climbing the antenna were detectable in both the incoherent and coherent AGC channel.

To find if the bursts in the incoherent AGC channel were due to IM products or wideband noise, another receiver with a 1 MHz bandwidth was tuned to a frequency between two IM products. The maser noise instrumentation subsystem was used to set the bandwidth and detect the noise bursts. Interfacing the noise instrumentation subsystem with the receiver recorder posed difficulties, but the data indicate that the noise bursts are broadband in nature, and correlate with the IM product amplitude (Fig. 14). Pointing the antenna at the collimation tower resulted in a drastic increase in both system temperature and IM product amplitude (Fig. 12). Offsetting the 2106.5517 transmitter frequency driver frequency 1 Hz (96 Hz change in transmitter frequency) resulted in the IM product receiver VCO frequency changing 38 Hz (IM product moved 3648 Hz). In a similar manner changing the VCO frequency of the 2106.5517 MHz moved

the VCO frequency of the IM product driver *down* in frequency 37 Hz.

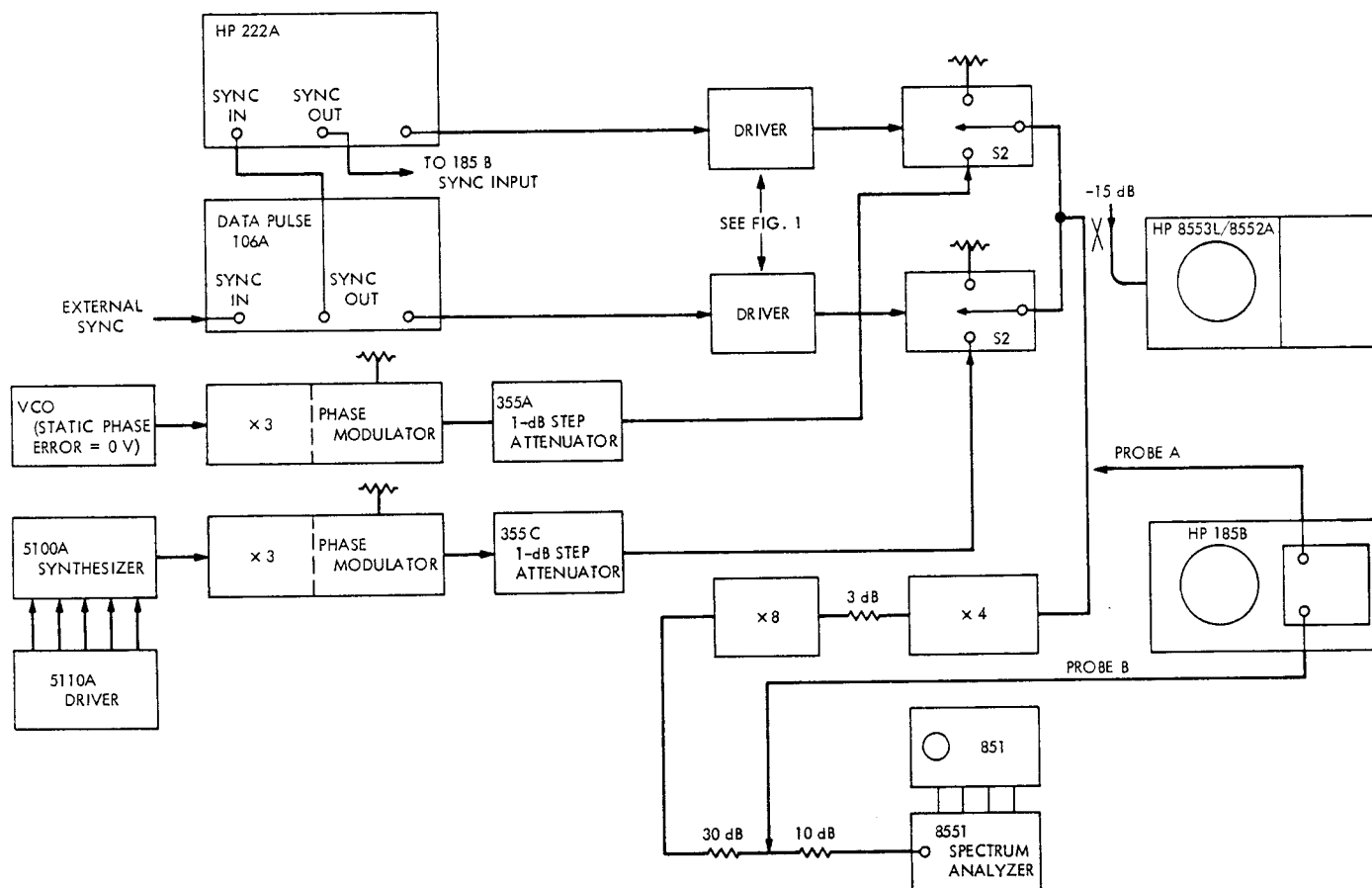
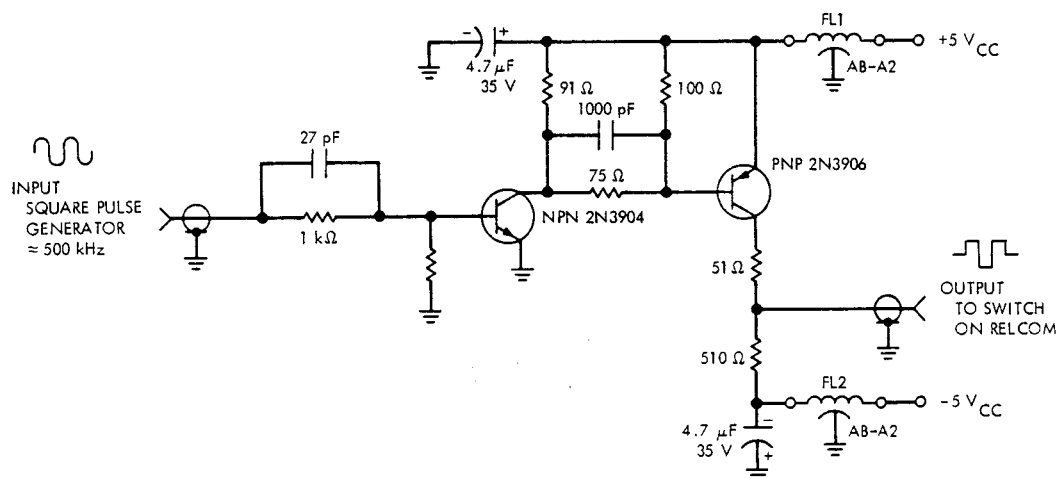
E. Future Experiments

Efforts will continue to produce IM products under laboratory conditions. From the experiments at DSS 11,

it seems that the same mechanism that produces noise bursts also produces IM distortion products. More controlled arcs and coronas will be used, as well as injection of various contaminants into the waveguide. Dual-carrier experiments at other DSIF stations will be made to determine the IM product problem's relation to the age and construction of the antennas.

References

1. Chernoff, R. C., and Hartop, R. W., "Noise and Intermodulation Interference in MSFN Back-Up Tracking Systems During Transmission of Dual Up-Link Carrier," in *The Deep Space Network*, Space Programs Summary 37-57, Vol. II, pp. 138-145, Jet Propulsion Laboratory, Pasadena, Calif., May 31, 1969.
2. Kolbly, R. B., "Switched-Carrier Experiments," in *The Deep Space Network*, Space Programs Summary 37-65, Vol. II, pp. 81-84, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 30, 1970.
3. Kolbly, R. B., "Switched Carrier Experiments," in *The Deep Space Network*, Space Programs Summary 37-66, Vol. II, pp. 84-88, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 30, 1970.



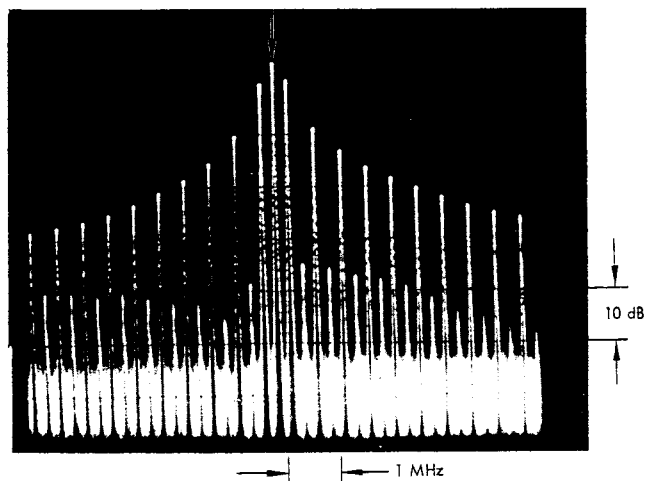


Fig. 3. Typical 66-MHz switched-carrier spectrum

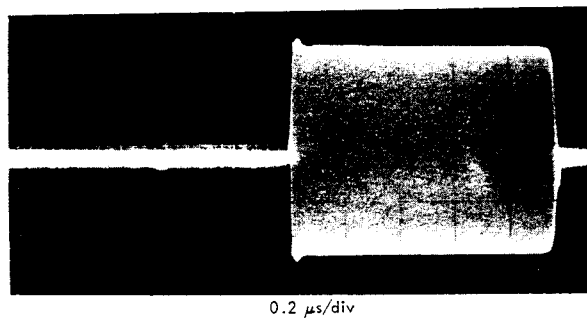


Fig. 4. 66-MHz single carrier

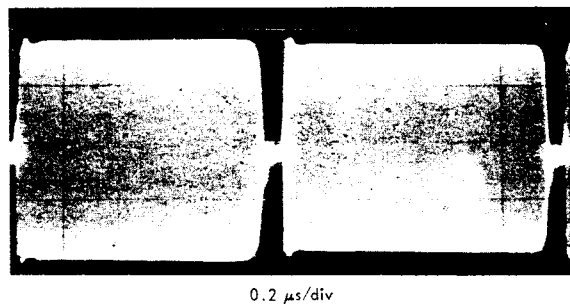


Fig. 5. 66-MHz switching (two carriers)

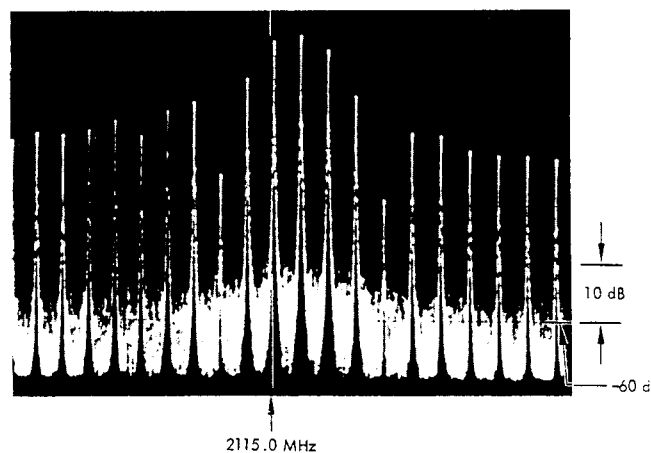


Fig. 6. Output spectrum of DSIF Block III multiplier chain

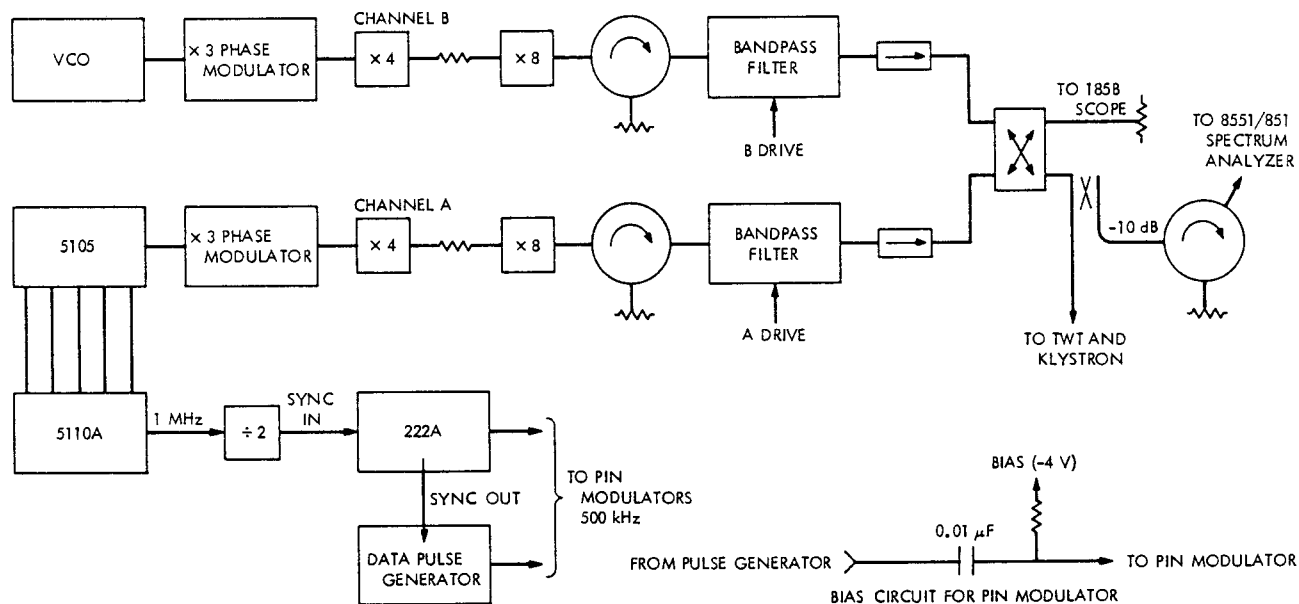
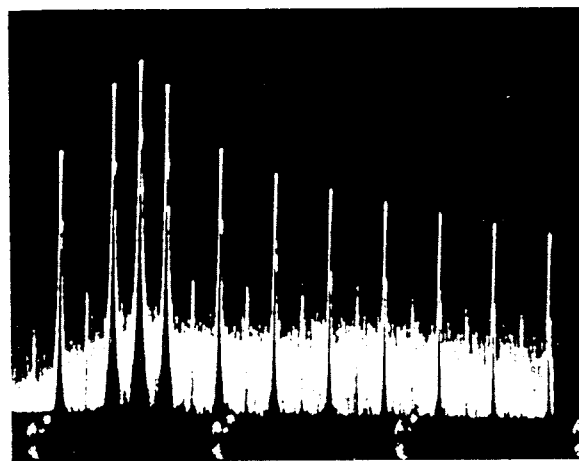
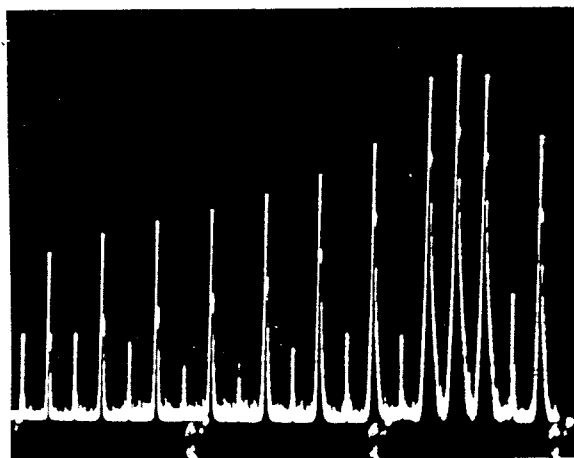


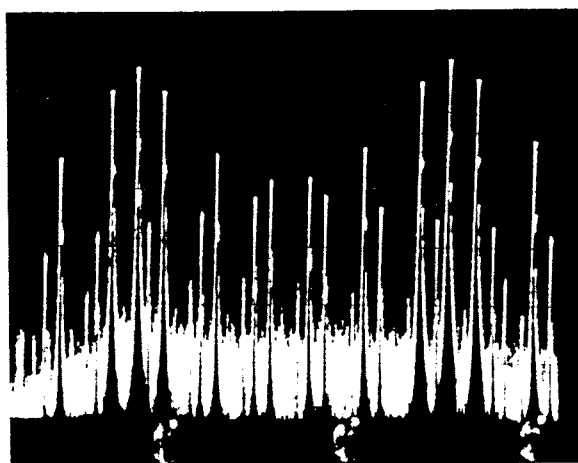
Fig. 7. Equipment configuration for switching at S-band



2110.0 MHz ONLY

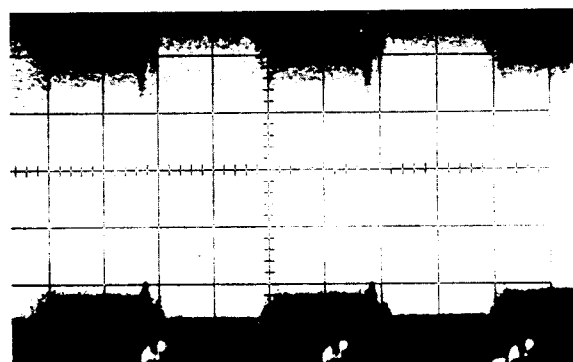


2115.7 MHz ONLY



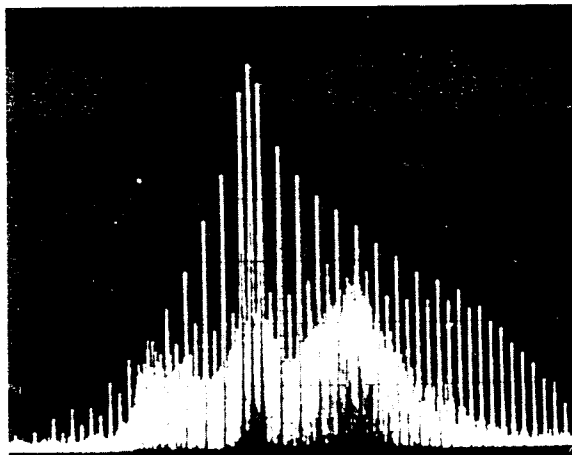
2110.0 AND 2115.7 MHz

Fig. 8. Spectra of drive signal with S-band switching

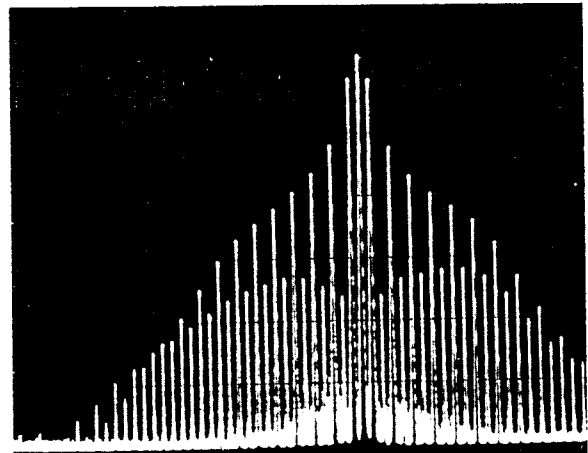


0.5 μ s/div

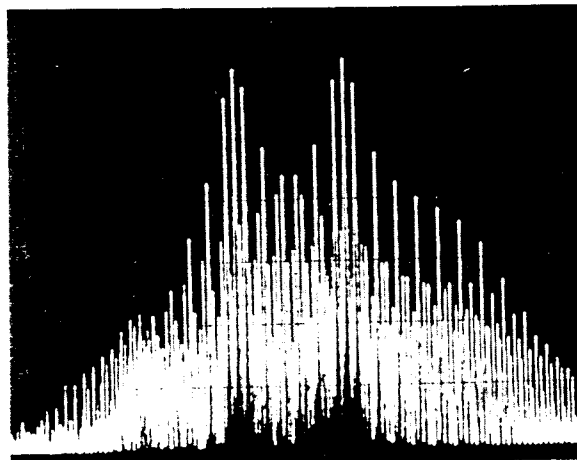
Fig. 9. Time domain display of spectrum in Fig. 8(c)



2110.0 MHz ONLY INPUT



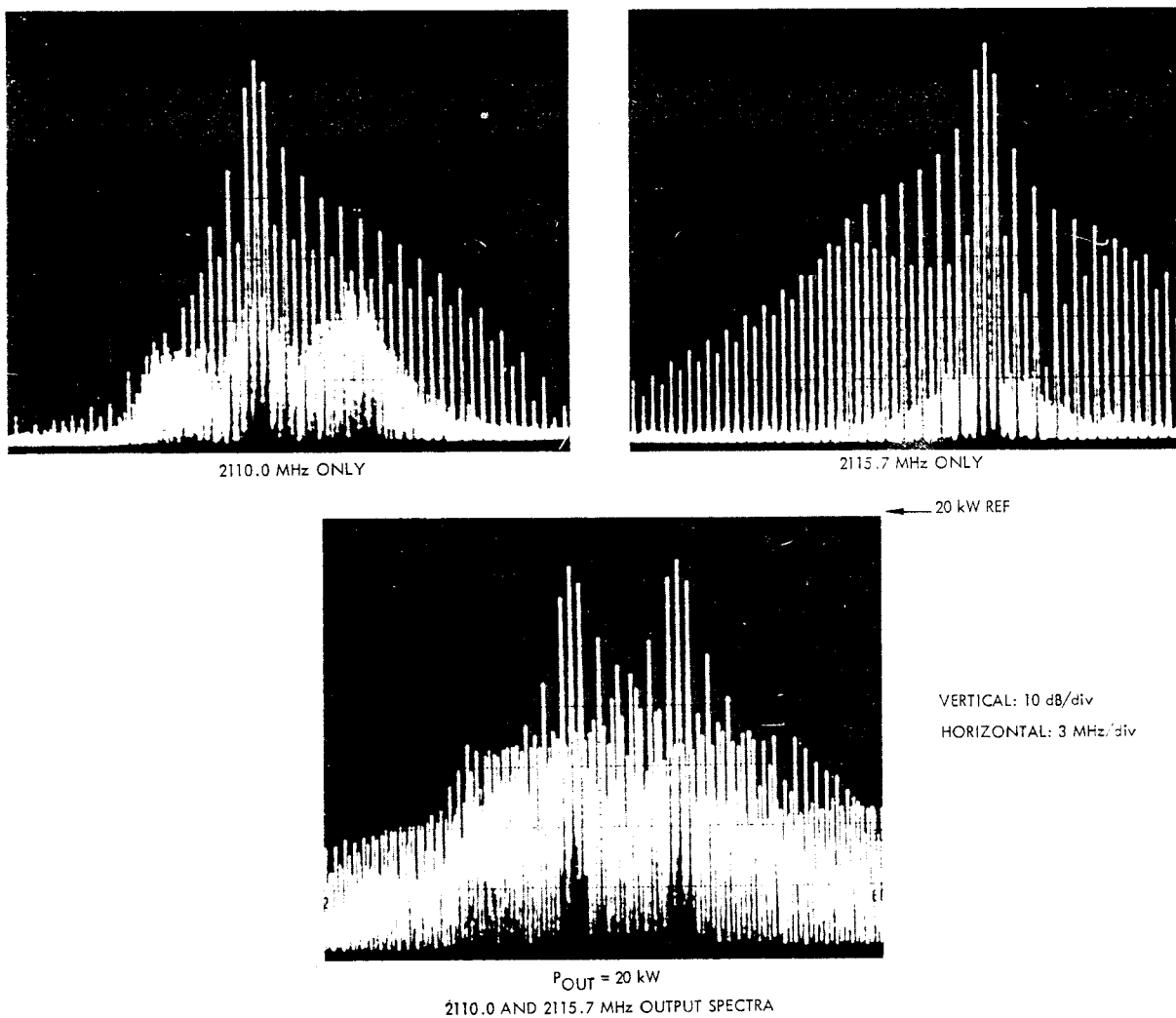
2115.7 MHz ONLY INPUT



2110.0 AND 2115.7 MHz INPUT

VERTICAL: 10 dB/div
HORIZONTAL: 3 MHz/div

Fig. 10. Input spectra to 5K70SG klystron



**Fig. 11. Output spectra of 5K70SG klystron; S-band switching, 500-kHz switch rate
klystron broadband-tuned**

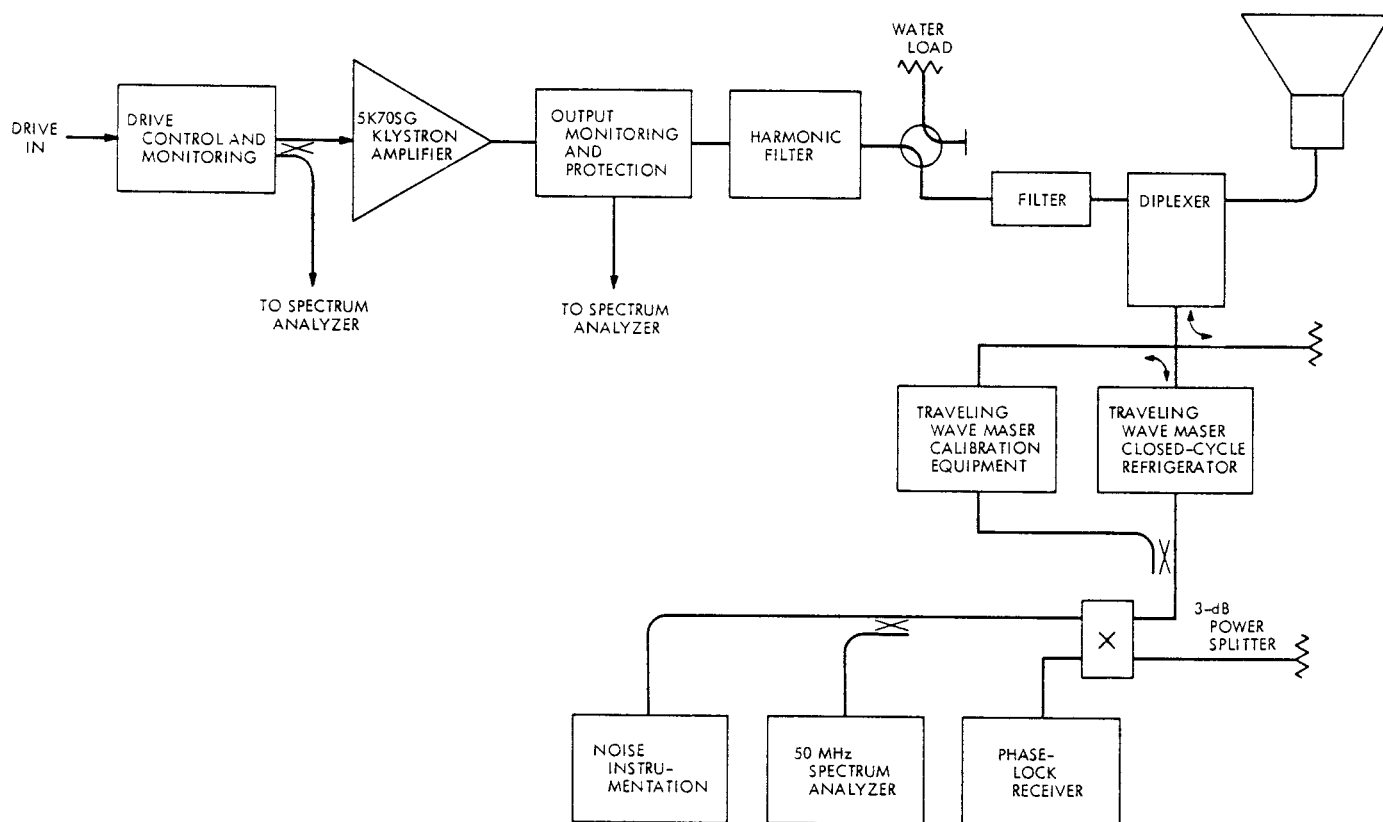


Fig. 12. SCM/TWM test configuration

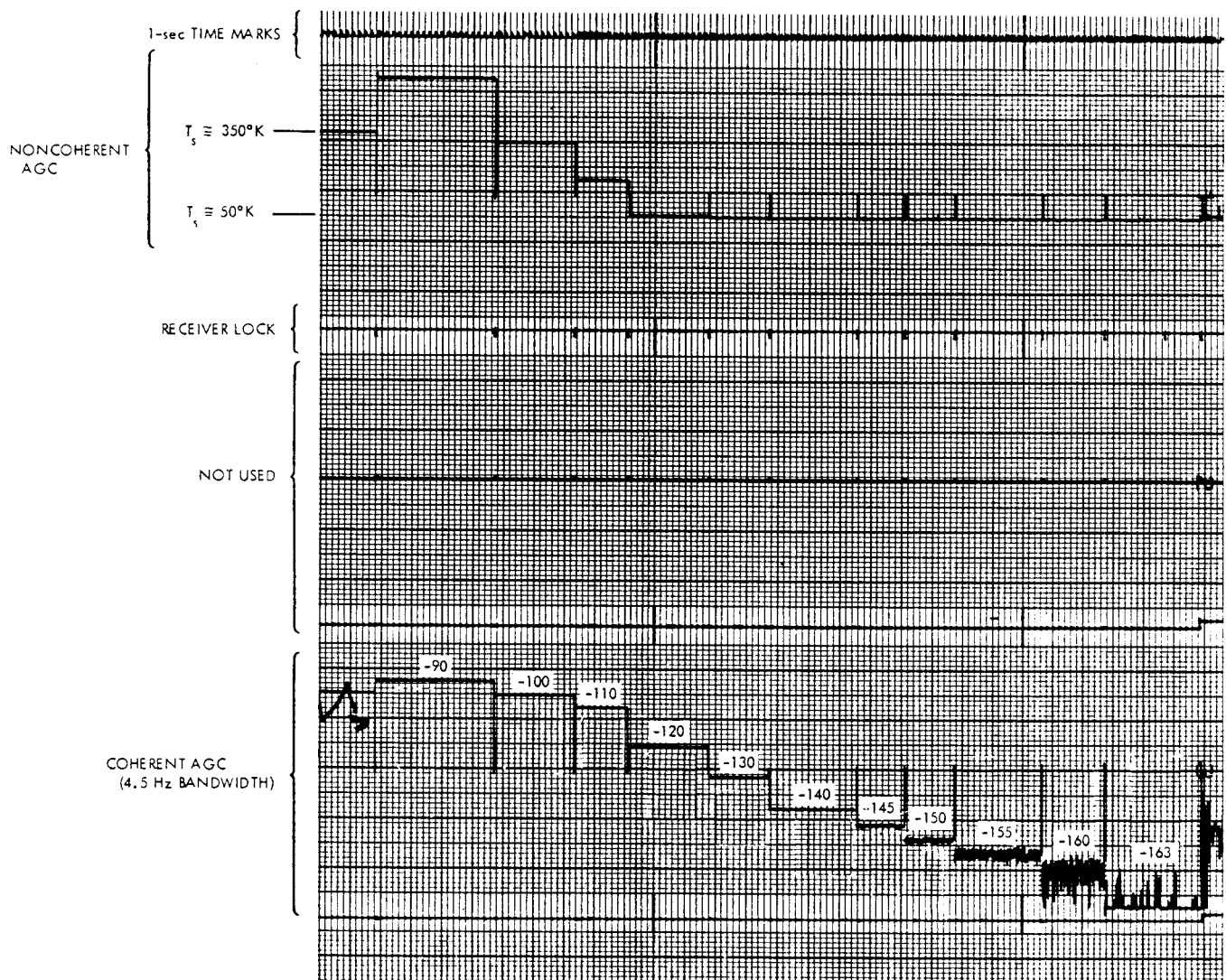


Fig. 13. Chart recorder output at DSS 11

IM PRODUCT
20-kW PER TRANSMITTER
(10-kW PER CARRIER RADIATED)

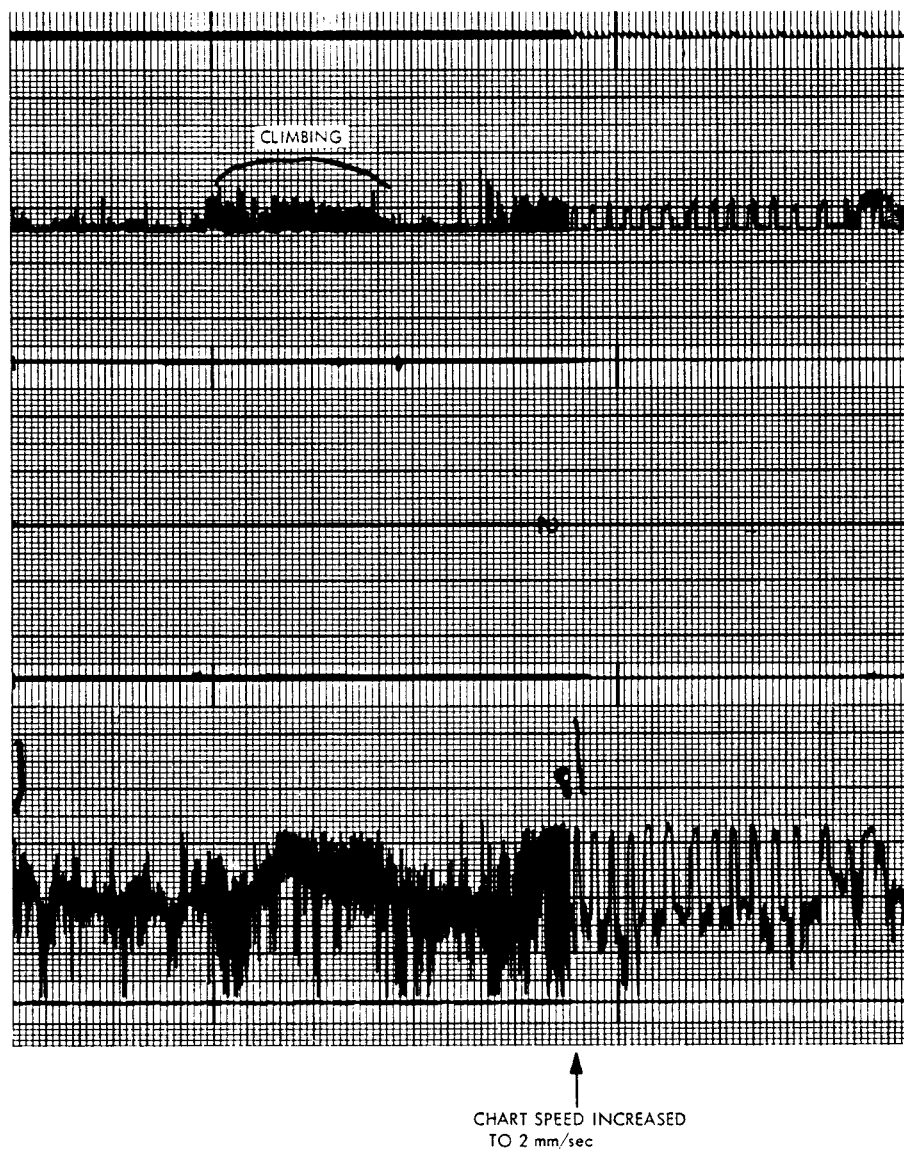


Fig. 14. Noise bursts and IM product amplitude at DSS 11

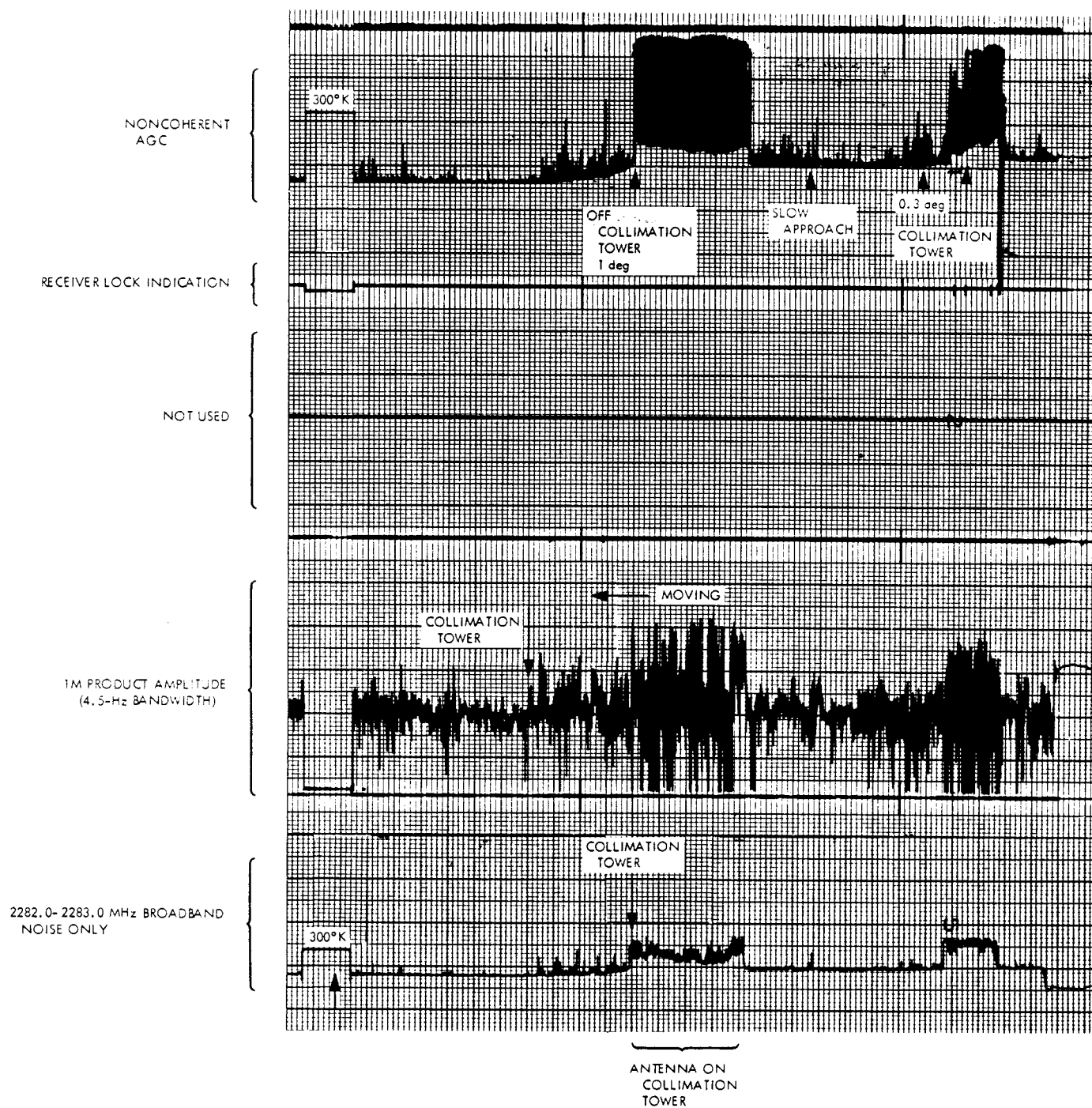


Fig. 15. IM product amplitude and broadband noise with antenna pointed to vicinity of collimation tower